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ABSTRACT

This article addresses the question: "What are the implications for the preparation of prospective elementary teachers of 'early algebra' in the elementary grades curriculum?" Part of the answer involves language aspects of algebra: in particular, how a change in pre-service teachers' attitudes to algebra, from instrumental to relational, is correlated with learning the conventional meaning of algebraic and other mathematical terms. (Contains 13 references.) (Author/MM)

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Changing Pre-Service Elementary Teachers' Attitudes to Algebra[1]

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In this article we address the question: "What are the implications for the preparation of prospective elementary teachers of "early algebra" in the elementary grades curriculum? As we discuss this question it will become clear that part of our answer involves language aspects of algebra: in particular, how a change in pre-service teachers' attitudes to algebra, from instrumental to relational, is correlated with learning the conventional meaning of algebraic and other mathematical terms.

Mathematics learning and teaching as procedures

Educators of pre-service elementary teachers face a constant challenge: their students' limited understanding of what constitutes mathematics and a mathematical approach to problems. Pre-service elementary teachers' attitudes to mathematics are generally instrumental, focussed on formulas and correct answers. Here are some illustrative remarks from our students:

> "… I was under the impression that finding a formula to solve a problem was, in reality, the answer to the problem."
>
> "I was used to having a formula and all I cared about was getting the right answer."
>
> "… we all came in with our preconceived notions of mathematics as simply finding a formula and getting the right answer …"
>
> "All throughout school, we have been taught that mathematics is simply just plugging numbers into a learned equation. The teacher would just show us the equation dealing with what we were studying and we would complete the equation given different numbers because we were shown how to do it."
>
> "As long as I could remember I have seen math as getting the right answer, and that being the only answer."
>
> (Quotes: pre-service elementary teachers at Harper College, Fall, 2000)

Pre-service elementary teachers are generally inflexible in their thinking, and rarely see connections between different problems or parts of mathematics. As they see mathematics so they are likely to teach it. Is this a bad thing? Smith III (1996), for example, argues that an instrumental approach to teaching mathematics provides a teacher with a robust sense of efficacy. Many pre-service teachers believe this is the only approach to teaching mathematics that will provide them with a sense of competence, proficiency, and know-how. What our experience tells us, however, is that they can see no other way. It is not that they have reflected on an instrumental, procedural style of teaching mathematics—an acquisition model (Sfard, 1998)—versus a conceptual, participation model and made a considered choice: they simply are not aware the conceptual approach exists (Davis & McGowen, 2001). But what is wrong with an instrumental, procedural approach to math-

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1. Published in Chick, Stacey, Vincent, & Vincent (Editors).(2001) *Proceedings of the 12th ICMI Study Conference: The Future of the Teaching and Learning of Algebra.* University of Melbourne, Australia. Vol. 2, pp. 438-446

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ematics, especially to algebra which is replete with rules and procedures? Gregoire (1999) provides an important part of the answer. In a detailed study of a grade 8 teacher she found evidence for a number of obstacles to learning. These obstacles—student misconceptions, irregular student achievement, student dependence, and lack of student self motivation—were associated with a predominantly procedural mode of teaching mathematics.

In graphic terms, a lesson to be learned from Gregoire's study, together with that of Smith III, is that a procedural approach to teaching mathematics helps the teacher feel more confident, but predisposes the students to dependence, lack of motivation, and misconceptions. When we focus on student learning, rather than teacher efficacy, this is not a happy state of affairs. How then might we encourage a more relational view of mathematics and what does this have to do with the teaching and learning of algebra in elementary schools?

Algebra as a meaningful experience

Our answer to these questions began with an example and led to a principle. We wanted to know how to enhance pre-service elementary teachers flexibility of thinking, and their ability to see and value connections. In so doing we focused on a particular case of a young student's beautiful experience in establishing connections between systematic counting and algebra (Maher & Speiser, 1997). This work, part of a larger study by Carolyn Maher, illustrated how Stephanie's memories of building block towers provided her with a visual model for binomial expansions in algebra. If a route from concrete manipulatives to syntactic algebraic expressions was available to one young student, might it also be open to pre-service elementary teachers? Our answer is "yes" (Davis & McGowen, 2001, McGowen & Davis, 2001) and it is from this answer that we draw a principle. The 19 preservice elementary teachers taught in Fall 2000 at Harper College, all underwent a substantial change in their views of mathematics. The principal agent for this change was the focus on building connections between different representations of a problem. How did these problems relate to algebra? These problems were variants of a single problem, involving binary choice:

- How many towers of height 4 can be made from blocks of 2 colors? How many towers of height 5?
- On the grid shown below, indicate on each dot how many different ways there are to walk to that dot from "home" given that you can only walk UP or RIGHT.

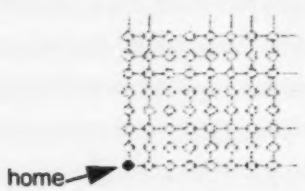

Figure 1. Portion of an integer lattice on which students performed walks Up or RIGHT from "home" to adjoining dots.

- How many different ways are there to run through a series of 4 tunnels if you must pass through exactly two white and two black tunnels?

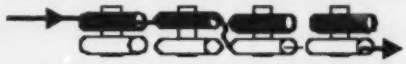

Figure 2: At each point, the runner goes through only a black or white tunnel.

- $(a + b)^2 = a^2 + 2ab + b^2$. What are the corresponding expansions for $(a + b)^3$ and $(a + b)^4$?
- What are the connections between towers, grid walks, tunnels and binomial expansions?

The problems we chose were unlikely to allow a solution by a remembered formula. For example, in relation to the problem of how many towers of height 4 can be built using at most two colors of blocks, one student wrote:

> "Instead of looking at it as a math problem, I was looking at it as a building exercise. I first attempted the problem by guessing and testing. Tony and I first attempted the problem of four high by creating combinations of four that would design an obvious pattern."

In our view the algebra entered in at least two ways. First, as a way of stating generalizations of building towers when students wrote 2^n as the number of towers of height n that can be made from at most 2 colors. In a later problem involving building towers from 3 colors, some students generalized their algebraic formulas:

"$3^4 = 81$, n = # of cubes high; x = # of color choices; formula: x^n.

Secondly, algebra entered the picture explicitly as syntactic algebra in the expansions for $(a + b)^3$ and $(a + b)^4$, the sort of syntactic expressions that most people associate with "algebra".

Except for one student this syntactic algebra was beyond them: they were unable to expand the binomial terms correctly. For the students, however, a different perspective developed on these syntactic expressions. One student speculated during class that there might be a connection between towers, grid walks and binomial expansions. He gave an explanation in class, prefaced by a statement along the lines "this might be crazy, but I think...," that $(a + b)^2 = a^2 + 2ab + b^2$ could be interpreted as saying something about block towers and grid walks. Namely, if a and b were interpreted as two colors, the binomial expansion says there is 1 tower of height two built from the "a" color, 1 from the "b" color, and 2 using both the "a" and "b" colors. The student used black (B) and white (W) and wrote the binomial expansion as $(B+W)^2 = B^2 + 2BW + B^2$. He then interpreted the same expression in terms of grid walks by taking B to mean "walk UP" and W to mean "walk RIGHT". Finally, he related towers and grid walks to the other binomial expansions, and the patterns of numbers on the grid to Pascal's triangle. The atmosphere following this student's presentation to the class was electric. The other students gave him a spontaneous round of applause and he, with four other students, stayed for an hour after class exploring these connections. This episode was etched into the memory of many of the students, as student write-ups and reflections show:

> "If you go through the tunnel with the pattern of *BWBW*, you can also make a tower of *BWBW*. If you think of B as equalling right and W as equalling up, you can go *RURU*. Algebraically, you can replace the a and b with a B and W and have $(B+W)$ raised to whichever high, which I'm using 4. It shows $(B+W)^4 = B^4 + 4B^3W + 6B^2W^2 + 4BW^3 + W^4$. If you add up all the numbers in front, you get the number of possibilities. The

> exponents are the number of the different colors you have. Ex: $4B^3W$ means there are 3 blacks and 1 white, with 4 different ways of arranging it. To have two of each like the tunnels ask, would be $6B^2W^2$, which means there are 6 possibilities with 2 black and 2 white."
> (Reflection, Week 4)
>
> "... although I used Pascal's triangle many times throughout high school, I never truly understood why it worked. By completing the grid walk exercises, so many things have become clear to me. Well, I learned the secret of the grid walks and of Pascal's Triangle.... I really wish I had known this when I was in Algebra. All we were taught then was that, for some reason unknown to me and probably many others in the class, the rows of Pascal's Triangle made up the coefficients in binomial expansion. Now I not only understand how to use the triangle algebraically, I know why it works. The numbers in an algebraic expression along with the variables can represent different groups of objects, in a manner of speaking. It all makes sense. This simple understanding, but by no means easy, is so rewarding because the knowledge has become my own. And I know that ten years from now, I will still be able to explain this problem."
> (End-of-semester write-up, week 16)

This interpretation of the syntactic expansions of the binomial expressions was used by many of the students in the solution of other problems. For example, in solving how many pizzas can be made from a base and 8 possible toppings, some students responded as follows:

> "n = without toppings; w = with toppings; $(n + w)^8$ = total combinations;
> coefficients = number in each of the subsets. Subsets = binomial coefficients"

What does this tell us? The semantic references for the binomial expressions $(a + b)^n$ have changed. Formerly, the references were at best *indexical* (Deacon, 1997)—a conditioned response, signifying nothing more than a way of acting in a given context. Now, the references for the binomial expressions have become *symbolic*, referring both to manifold objects and processes, as well as to other syntactic marks, such as $6a^2b^2$. Students now see $(a + b)^n$ as a binomial, representing two choices in the context of these problems. Without wanting to delve too much into semiotics, we feel that the common term "mathematical symbols" to refer to squiggles such as $(a + b)^n$ glosses over the deep interpretation and shift in thinking that takes place when, as for these students, the squiggles become genuinely symbolic—symbolizing something:

> "When we started with blocks I still remember thinking, 'There has to be an easier way of doing this. I need some sort of an equation or something and that's it.' I never realized how important, especially for children, it is to visualize things. Especially when it comes to math. When we finally figured out the equation it was kind of like I could see it being done on the blocks in my head. Also I understood that the blocks were a representation of the powers of two."

The issue is a simple one—do the signs and squiggles mean something in a deep, satisfying, human sense or do they merely indicate actions to be carried out, as when we say "sit!" to a dog? This is a linguistic issue, for language is not simply a collection of marks to which we respond, as if conditioned to do so. It is also a means for expressing the ability of our brains to see and value connections. For these teachers, algebra in the form of exponential functions and binomial expansions was no longer a series of marks signifying only that they should do something ("simply just plugging numbers into a learned equation", for example). Algebra and algebraic language now became a means of expressing relationships between objects and processes—a way of talking

about and describing experiences in pattern and arrangement. The algebraic formulas, such as $(a + b)^4 = a^4 + 4a^3b + 6a^2b^2 + 4ab3 + b4$, developed meaning via manifold references.

Early algebra

We need to say something about how we envisage "early algebra". The relevant student population consists of students in grades 5 through 8: the last two years of elementary school through the next two years of schooling. Kaput (2000) and Kaput & Blanton (2000) identify five main strands of algebra:

1. (Kernel) Algebra as generalizing and formalizing patterns & constraints, especially, but not exclusively, algebra as generalized arithmetic reasoning and algebra as generalized quantitative reasoning.
2. (Kernel) Algebra as syntactically-guided manipulation of formalisms.
3. (Topic-strand) Algebra as the study of structures and systems abstracted from computations and relations.
4. (Topic-strand) Algebra as the study of functions, relations, and joint variation.
5. (Language aspect) algebra as a cluster of (a) modeling and (b) phenomena-controlling languages.

As a basis for early algebra we consider Kaput's kernels—algebra as generalizing patterns, and as manipulation of syntactical forms. To these we add a third element: *interpretation of syntactical forms*. Maher and Speiser's (1997) description of Stephanie's interpretation of the binomial expansion of
$(a + b)^3$ in terms of towers of height 3, is a classic example of what we mean by interpretation of syntactical forms. The Concise Oxford Dictionary (Oxford University Press) defines "interpret" as:

(a) explain the meaning of (foreign or abstruse words, a dream, etc.).

(b) elucidate or bring out the meaning of (creative work).

(c) act as an interpreter, esp. of foreign languages.

(d) explain or understand (behavior etc.) in a specified manner (interpreted his gesture as mocking).

The Latin root of "interpret" is "interpretari" — to explain or translate, from "interpres —pretis", explainer. Thus, to interpret is to make clear or intelligible. A significant aspect of interpreting is to reconstruct the semantic meaning of syntax in another form or language: what might be unintelligible squiggles to us in Sanskrit can be translated to allow us to make sense of it in our own language. This interpretive aspect of algebra is what so affected our pre-service elementary teachers: the binomial expansions were not, as they previously thought, meaningless syntactical manipulations, but in fact had significant interpretations. These interpretations began to provide meaning for the binomial squiggles, and so helped students to view them, and other mathematical squiggles and operations, symbolically:

> "Symbols have different meanings depending on where they are written."
> "I know that I don't truly understand a math problem until I understand the algorithm, have correct computation, and am able to justify my answer."

"Overall the reflections on our work really made me put everything together and get a better understanding and meaning of what it is to do mathematics."

"Before taking this class, I would think mathematics is about only dealing with solving the problems using numbers. When I took this class, I realize it is not just dealing with numbers, but the actual meaning of all the problems."

"The meaning of arithmetic operations is quite simple once all the connections are understood."

We emphasized the building of connections in the pre-service teachers course. The express aims of our teaching method were to break up their notions of mathematics as consisting solely of applying formulas to get an answers, and to provide experiences for them that increased the flexibility of their thought. Younger, largely pre-pubescent, children will generally be more flexible in their thinking than adults. In order to foster and maintain flexible thinking in their students, teachers need to be able to think flexibly themselves. The problems we used with the pre-service teachers in the first 3 weeks were capable of precise translation from one to another. Such translations—from towers to grid walks, for example—required the development of a dictionary. Once that dictionary was in place students could and did rapidly re-interpret one problem situation in terms of another, gaining insights into both problems in the process. Algebra requires, however, that we are capable of other, less visually direct, interpretations. For example the identity:

$$a^2 - b^2 = (a - b)(a + b)$$

is capable of interpretation in a number of ways, including an analogy with factorization of whole numbers (relatively easy, but not visually imperative), and as a saddle being a product of two planes (hard, but visually striking). What assists in building meaning for algebraic formulas is the flexibility to look for multiple interpretations. Often these interpretations are not obvious. They require study, thought, and the sharing of experiences.

The important criteria for us, therefore, for early algebra, are the following:

1. Generalizing patterns of number, space and arrangement.
2. Manipulating syntactical forms.
3. Interpreting syntactical forms through connections between patterns and syntactic forms.
4. Maintaining and enhancing flexibility of thought through actively seeking interpretations of syntactical forms.

Early algebra for us is not only a list of topics or general aspects of mathematics: it is also an attitude to mathematical thinking, one that emphasizes connections and flexibility of interpretation.

What might help pre-service teachers teach early algebra?

In our experience pre-service elementary teachers need to move from one ball-park to another. They first need to be brought face-to-face with their unexamined belief that mathematics is only about applying formulas to find answers. Problems as simple as enumerating all towers of height 4 and 5, built with one or two colors, are sufficient to set this process in motion. Our pre-service teachers abandoned what they saw as a "mathematical approach" to the towers problems and experimented instead:

> "When I looked at the towers, I never thought about there being a simpler way than building them all individually."

They were brought up sharply by watching a video clip of Stephanie (Maher & Speiser, 1997) and other grade 4 students arguing why they had enumerated all possible towers:

> "They talked through the problem very well and explained it to each other better than I'd be able to."
>
> "... Milin saw the pattern that if the tower is three high, and that there are two blues, three different possible towers can be made with the red cube in a different position each time. I now realize that there are several patterns and options to solving this type of problem. Each of us in class recognized patterns, but not one formula could clearly explain or define our cases."

They were encouraged to explain individual insights to the entire class, and they valued the insights of others:

> "Through class discussions, I learned that in order to be successful in mathematics, not only do you need to internalize what you learn, but you also need to think about the most appropriate method to solve the problem."
>
> "... we had to solve the number of possible solutions or ways from home. After physically counting the first three rows, classmates noticed patterns again. This time we realized that you only need to add the number of paths that are required to reach the point exactly above."
>
> "Tunnel travel led us to a new discovery.... After analyzing the answer or expansion, James (in class) recognized the 1, 4, 6, 4, 1 pattern. This is the number sequence from Pascal's triangle which maps out the different color combinations from the tower building of 4 high, 2 colors. All of these exercises relate in the fact that they are algebraic expansions."

The pre-service teachers also related their own learning to that of the children they hoped to teach:

> "We all struggled to forget our own preconceptions of teaching mathematics by examining the learning process. But with this struggle came the crucial lessons that are forever cemented in our minds. Not only do children need to be allowed to learn at their own pace, not only do we as teachers need to treat each child as an individual, but most importantly, it is up to us as elementary school teachers to help them understand the importance and reasoning of mathematical understanding of the root of the concept."

They read two articles of critical importance: Skemp's (1976) paper on instrumental and relational knowledge, and Chapter 3: Generating Representations: Division by Fractions—of Ma's (1999) book on teaching elementary mathematics. These readings were important for them:

> "The readings by Richard Skemp and Liping Ma opened my eyes to a new outlook on mathematics. I have never before thought about where mathematical theories come from."
>
> "Reading Liping Ma's work sparked my interest about approaching mathematics from different angles, an idea I had never considered before. Ma forced me to look at my current knowledge and understanding of fractions....I realized that I rush into problems often without thinking of the most appropriate method to solve."

Finally, they all increased their mathematical content knowledge and basic mathematical competence. An initial competency test and a final examination, incorporating many of the problem types of the initial test, were administered to the students. We calculated a *shift statistic*, defined, as follows:

$$shift = (\text{final test\%} - \text{initial test\%})/(100 - \text{initial test\%})$$

We interpret *shift* as how much a student has moved form their initial test result to their final test result. A student who has a relatively high initial test score does not have as much room for improvement as a student with a low initial test score. However, since the shift statistic takes into account a student's *potential for growth*, it is possible that any student can attain the highest shift, 1.00. Shift values ranged from 0.91 (with a maximum possible of 1.00) to 0.13; in particular, all were positive. The mean shift was 0.56 and the standard deviation 0.19. A paired 2-tailed t-test on the initial and final test scores showed a highly significant increase ($p < 5 \times 10^{-8}$).

What is the alternative to training (we refrain from writing "educate") elementary teachers who fail to see algebra as having meaning, but who know how to push syntax around? We suggest these experiences described in this paper are repeatable (that hypothesis is currently being tested at Harper College) and can be taken as the basis for a set of teaching experiences that help place pre-service elementary teachers in the right ball-park for teaching early algebra. In summary, pre-service elementary teachers can become more effective teachers of early algebra by:

1. Facing their unspoken attitudes to mathematics being all about using formulas to get correct answers.
2. Seeing children solve problems that they themselves struggled with.
3. Seeing and hearing other pre-service teacher's insights into mathematical solution processes and thoughts.
4. Being asked to continually and actively seek out connections.
5. Practising interpretation of syntactical forms in more concrete terms.
6. Reading and discussing mathematics education literature that speaks to their learning styles and content knowledge.
7. Constantly adding to their content knowledge and relating it to previous mathematical knowledge,
8. Relating their learning to that of their prospective students.

A tall order? We think it is achievable. The 19 students in the Fall, 2000 course for elementary teachers at Harper College who completed the semester achieved these goals in varying measure.

> "This process of teaching gives the student a true understanding of mathematics. Not only did we get the answers, we made connections with other ideas. That is a true way of learning mathematics and what it means. All the learning I accomplished was taught relationally. Math isn't just about getting an answer."
>
> "From the beginning of the semester on, problem solving was the main source of working though class material. From problem solving came the goal of building connections. Connections to powers of two and subsets came through the use of the concrete manipulatives to assemble towers."
>
> "Without a solid understanding of the concept behind the algorithm, a students hasn't really learned anything, just memorized an equation."
>
> "I have learned that mathematics is indeed a series of interrelated ideas. I was challenged to extract these connections from our daily work while acquiring new skills in mathematics."

"If I had been asked to make these connections back in high school, I probably could not have done it. I succeeded at these exercises because of our group discussions and Jim's recognition of the 1, 4, 6, 4, 1 pattern of Pascal's triangle."

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Note: A complete set of problems used in the course is available in pdf format from mmcgowen@harper.cc.il.us.

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